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HAZARDOUS WEAR PREVENTION SYSTEM FOR FRICTION UNITS OF GAS  
TURBINE ENGINES

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**Abstract:** The hazardous wear prevention system is comprised the automated continuous monitoring system of gas turbine lubricated friction units, the operation of which is based on the change in the number of wear particles, as well as the average wear particle size in oil. The system includes the cyclonic separator, self-cleaning sensors from ferromagnetic particles, the control unit and the measured data accumulation unit.

The system's sensor is installed in the case of cyclonic separator of the wear particles that is incorporated in oil scavenge line.

The sensor's operation is based on the well-known principle of the ferromagnetic wear particles accumulation between the two totally isolated from each other magnetic (plus and minus) poles. They are at the same time used for ensuring the electrical contacts. In case sufficient electroconducting ferromagnetic particles are accumulated the contacts are shortened.

A completely new sensor's design, new algorithmic equations and the measured data processing allow to increase decisively the sensor's sensibility and to apply it for measuring the ferromagnetic wear particles velocity multiplied by the average size under the real time condition.

The paper presents the first tests results of the hazardous wear prevention system as a part of PS-90GP gas turbine engine.

**Keywords:** Monitoring; particles; pole; sensor; separator; system; wear.

The field experience has demonstrated that the automated continuous quantitative monitoring of debris (AQMOD) as well as of the wear particles sizes washed out from the surface of the friction units is one of the most promising and perspective modern diagnostic method used for condition monitoring of the friction units in gas turbine engines (GTE).

For quite a long period of time the method of monitoring wear particles in GTE oil was being developed based on the improvement of devices and methods applying electrical ferromagnetic chips detectors (ECD). But however less interest has been revealed for the development of the systems based on ECD and to the instruments applying ECD of the latest generation (demagnetizing chip detector (DCD) which were never used for practical purposes after the invention of firm Tedeco. It has developed a new quantitative monitoring method of particles (QDM) applying the magnet inductive sensor of the accumulative character.

But however DCD has certain advantages and a new approach to the design and the method of applying it can allow the creation of effective AQMOD on their basis.

The current paper presents some properties of DCD sensors, peculiarities of it's design and the preliminary test results of AQMOD with contact sensor magnet controled, which has been specially designed for PS-90 GP engine.

#### **PREREQUISITES FOR DEVELOPING THE SYSTEM**

The first AQMOD with the applied DCD was designed in 1978 [1]. Two iron electromagnetic pole pieces with the gap between them served as the sensitive elements of the sensor's system. The gap had the shape of the slot and

was  $\delta$  wide. The magnetic poles pieces were isolated from each other and performed the role of sensitive electrical contacts. Following the appropriate command of an auxiliary electronic unit the magnetic poles pieces could be magnetized or demagnetized.

In case the magnetic poles pieces were in the magnetized status ferromagnetic particles being moved by the oil flow could be captured and arranged in the chain between magnetic poles by the magnetic field. As long as the length of the line reached the size of the gap  $\delta$  the poles-contacts of the sensitive elements were shortened. In case the magnetic poles pieces were demagnetized the particles were washed out and carried away by the oil flow.

The demagnetisation command was sent after equal periods of time  $t_0$  from the timer and was not related anyhow with the detector of shortening the contacts of the sensitive elements of the sensor. The magnetization of the magnetic poles pieces was performed automatically following the demagnetization after a short period of time which was necessary for removing the accumulated particles. In case time  $t_\delta$  (needed for the formation of the shortening chain) was higher than the set time  $t_0$  the shortening of the contacts did not occur during the sensor's operation, as the growing chain collapsed long before they could reach the length  $\delta$ . While the particles in oil grew in number time  $t_\delta$  decreased. When  $t_\delta$  becomes less  $t_0$  the sensor activated sending the signal about shortening to the memory of the auxiliary electronic unit.

In case the time between two sensor's activations was less than  $t_0$ , which is an evidence of the non-random character of the activations, the auxiliary electronic unit was sending signals of alarm irrespective of the further behaviour of the sensor.

The device could be adjusted for any set level of wear particles quantity in oil, by just adjusting the value  $t_0$ .

The described device is of a threshold character and does not allow to monitor wear processes trend, which deprives the user of the possibility to estimate adequately the importance level of the sent warning signal and to prognose the residual life time of the monitored unit. Most probably that was exactly the disadvantage which did not allow it to compete with QDM [2] which was designed two years later and was well recognized.

But however DCD can be applied with a success in AQMOD systems if the control of the sensor's unit will be changed and effective algorithms for processing the measured data will be used.

Let us consider the physical phenomena to which DCD responses.

The magnetic field that is located across the sensitive sensor's gap, determines the location of the particles in the area: there is an attempt of the particles to arrange themselves along the magnetic force lines forming chains of particles making them as long as possible by being connected along their shortest sides. Assuming this is true the number of particles in the chain is big enough irrespective of the spectrum distribution mode of the biggest particles sizes the average velocity of shortening the chain will be equal:

$$v = k \cdot v(t) \cdot l(t)$$

where  $v(t)$  and  $l(t)$  - the average frequency of the particle's arrival and the average length of the particle, approaching the area of the sensor's location from the monitored unit under real time  $t$ ;

$k$  - the coefficient of particles flow fullness. It is equal to the ratio between the number of particles which formed the shortened chain and the total number of particles coming to the area of the sensor's location within the period of time when the chain was formed.

As the transformation of the normal wear mode into the accelerated wear mode by all means is accompanied by the increase in  $v(t)$  or  $l(t)$ ; and it is a more frequent case

when the growth of both values is observed, the increase of  $V$  is a good criterion for revealing the intensive wear of the monitored unit.

Dividing value  $V$  by the width of the operated gap  $\delta$  one arrives at:

$$V/\delta = 1/t_{\delta}$$

based on the above equation it becomes clear that if the commanded by the timer cleaning of the sensor is omitted and the cleaning of the sensor is done only following the sensor's command, then in case of the stationary character of the monitored process the sensor's activation will be done with the constant average frequency  $f=1/t_{\delta}$ , which is proportional to the established level of the wear intensiveness. Due to this it may be stated that the system with such type of control of the sensor and the measurement of the average frequency of it's activation is capable of monitoring linier slowly changing trends that can be presented as  $v(t) \cdot l(t)$ . The system AQMOD can be created using the principle similar to the above, but with an exception that sliding non-linier algorithms should be applied for processing current values of  $1/t_{\delta}$ . This will allow to reveal the non-linier relatively quickly changing trends for the conditions under which the oil is contaminated by foreign lengthy particles which cause the false activation of the sensor.

DCD sensor has the integrating character which explains it's certain properties and capabilities. The proper choice of the gap's working width will provide the flexibility in adjusting it for the wear processes that are typical for different engine types. For example, in case the oil is finely filtered DCD could be adjusted for operating aimed at small size particles within the sizes range that can not be detected by QDM systems. But however in comparison with the latter, DCD system will ignore big-size single particles which can be found in oil as a result of a sudden hazardous failure in the unit being monitored.

The possitive feature of DCD is explained by it's capability to be operated within the wide range of dynamic flow of ferromagnetic particles. Due to it's capability of self cleaning it will operate normally under the condition where the sensor of QDM system will be overaccumulated by particles too quickly. At the same time if the tendency to the critical trend growth is observed DCD can be deliberately switched off (under the status of magnetisation) for accumulating wear particles for the laboratory analysis. And for all that the particles accumulated by the sensor will be meaningful in the contrast with the particles accumulated under the same conditions by QDM sensors.

The disadvantage of DCD in comparison with the QDM system sensors is explained by it's lower sensitivity due to the smaller coefficient of particles flow fullness.

#### THE SYSTEM'S DESIGN

The hazardous wear prevention system for the friction units (HWPS) is designed for the operation as a part of the gas pumping station drive on the basis of PS-90 engine. The system's sensor is installed in the case of the cyclonic separator of the wear particles that is incorporated in oil scavenge line. The separator's design allow the spiralled oil wash out the surface of the sensitive element providing the easy removal of particles used by the sensor.

The magnet field in the gap area of the sensor is created by the constant magnet which has relatively a low coercive force which allows to remagnitize it applying a small-size coil energised by the pulsating current. As the sensor most of it's time is being operated in the mode of wear particles accumulation the appliacation of the constant magnet instead of the electrical magnet decisively reduces the average consumed energy of the system. Within the period of demagnitisation-magnetisation which is 2,5 sec HWPS consumes about 3 wt.

The sensor's signals reach the registrator where they are being constantly registered and along with it they come to the unit of the measurement data processing which specifies the trend of the intensiveness criterion of the friction units wear and provides monitoring of it's changes. The trend is specified by the consequent processing of the reversed intervals values between the sensor's signals using the method of exponential smoothing sliding medians. In case of the constant tendency towards the trend growth the unit sends the alarm signal. The operation of HWPS is not interrupted during the entire period when the continuous signal is being sent.

#### THE RESULTS OF THE PRELIMINARY SYSTEM'S TESTING

The operation of HWPS was tested in the laboratory of the drive's designer, the testing rig for GTE oil system sensors and fittings was used. The separator with the sensor was installed in the oil scavenge line.

The main objective of the experiment was to estimate HWPS relative sensitiveness to small-size (less than 0,2 mcg) and medium-size (up to 2,5 mcg) ferromagnetic particles. Small size pieces of the steel chips being 20...50 mcm in size and about 10 mcm wide were used to simulate small size particles. Medium-size particles were represented by steel chips pieces being 100...150 mcm in size and about 15 mcm wide.

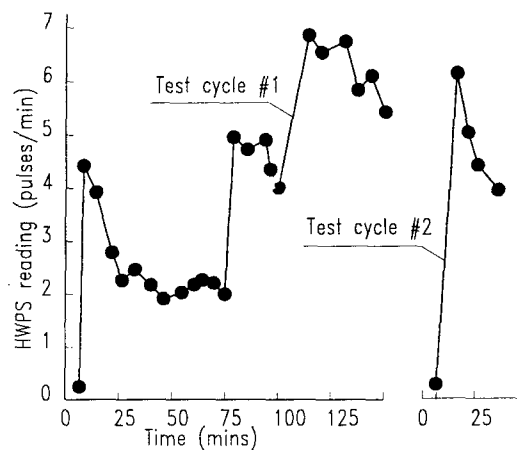
The experiment was conducted in two cycles. During the first cycle HWPS was operated applying small-size chips, during the second period - medium-size chips. There was no change of oil when transiting to the second cycle of the experiment. The oil was cleaned each time before starting the next cycle applying the removable filter and the removable magnetic catching device. The oil volume in the oil system was equal to 25 l, the oil consumption - 28 l/min. The pressure drop on the separator was equal to 0,3 kg/cm<sup>2</sup>.

Chips were injected inside the oil tank in portions, 300 mg each.



Three portions of small-size chips were injected during the 1 cycle of the tests: the first portion on the 10-th minute of the cycle, the second one - 75-th minute, the third one - 100-th minute. On the 10-th minute of the second cycle the medium-size chips portion was enjected.

The picture presents the tests results.



Points used for drawing the curves corresponded to the average in time number of sensor's signals that were registered on the consequent 5-minutes intervals on the register tape.

HWPS was monitoring and registering both the initial background of the residual ferromagnetic debris of the

circulating oil as well as the resolution processes of the concentrated chips gradients injected in the oil tank.

So HWPS can be operated with a far more finer wear particles (0,2 mcg; 50 mcm) being compared with QDM which can register particles the mass of which is more than 5 mcg and that are more than 250 mcm in size [3]. The results of the experiment do not allow to estimate the HWPS sensitivity threshold as the used chips portions were too big. The necessary data will be obtained in the process of the further study and the system development for the engine.

#### SUMMARY

The combination of self demagnetising contact sensor with the cyclonic separator allowed to develop a new system for monitoring wear particles in GTE oil. This system is less sensitive than QDM, but however it is good enough

for a more wide dynamic range and can be applied for the wear particles spectrum which is expanded finer sizes oriented.

The results of the preliminary tests give hope that after the system will be developed on the engine it will respond to any abnormal wear of the monitorred friction units which are characterised by the accelerated formation of ferromagnetic wear particles, being 20 - 50 mcm in size.

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